Observing Global Precipitation TRMM, GPM, and beyond

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(w. material borrowed from many)

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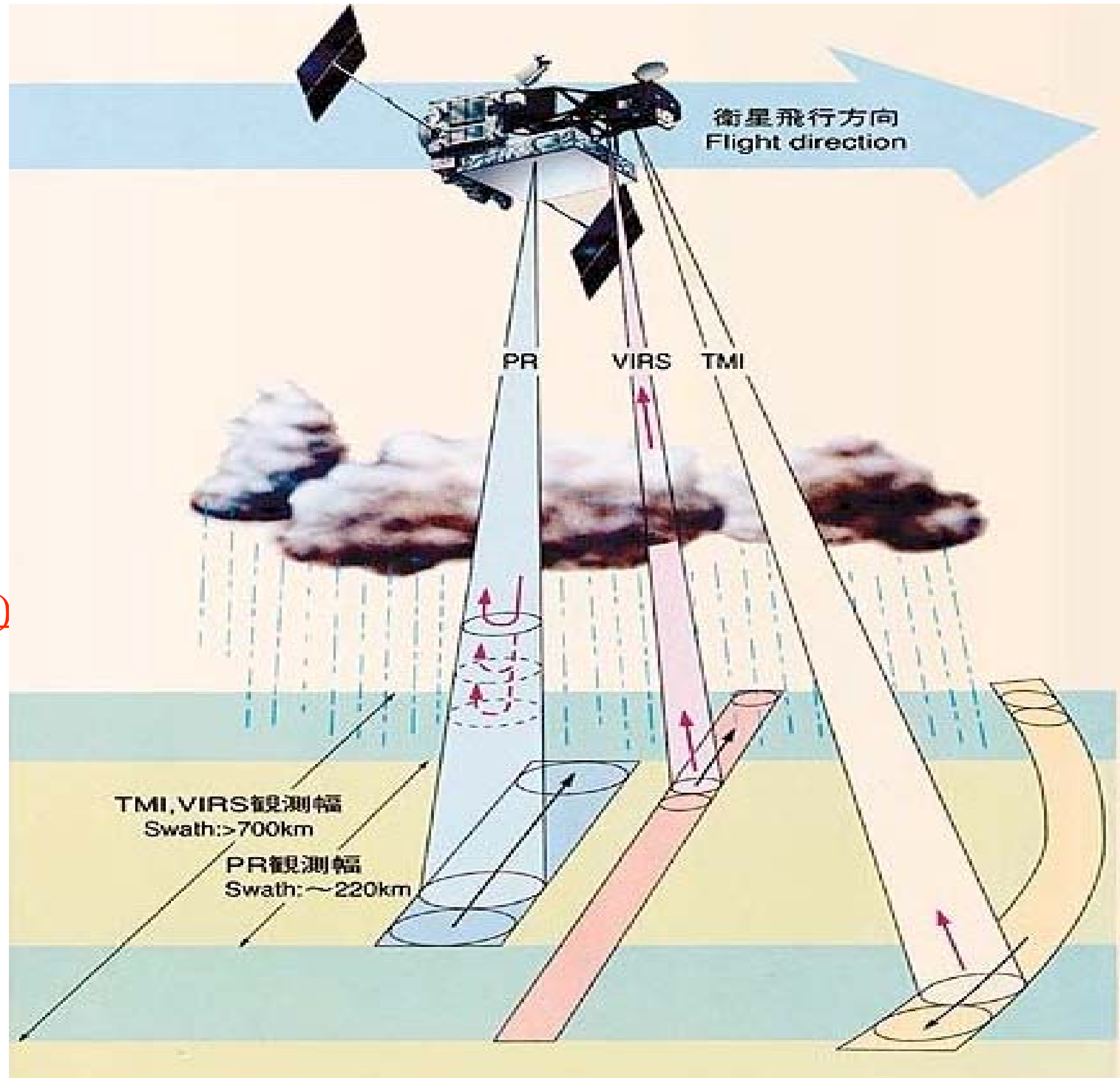
Tropical Rainfall Measuring Mission (TRMM)

NASDA
NATIONAL SPACE DEVELOPMENT AGENCY OF JAPAN

TRMM Sensors

Nov. 1997 launch, 35° inclination; 402 km



Precipitation radar (PR):

- 13.8 GHz
- 4.3 km footprint
- 0.25 km vertical res.
- 215 km swath

Microwave radiometer (TMI):

- 10.7, 19.3, 21.3, 37.0
- 85.5 GHz (dual polarized except for 21.3 V-only)
- 10x7 km FOV at 37 GHz
- 760 km swath

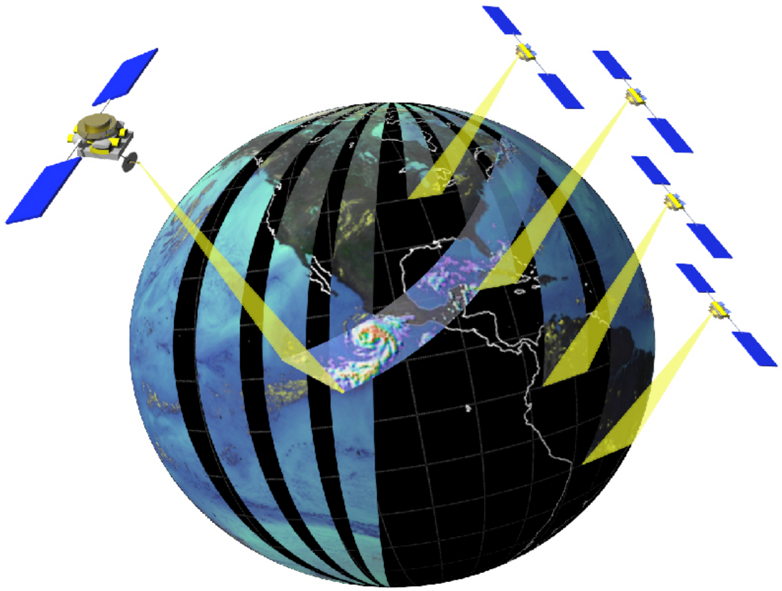
Visible/infrared radiometer (VIRS)

- 0.63, 1.61, 3.75, 10.8, and 12 :m at 2.2 km resolution

Lightning Imaging Sensor (LIS)

Cloud & Earth Radiant Energy System (CERES)

The Global Precipitation Mission (~2008)



CORE SATELLITE

- Dual frequency radar
- Multifrequency radiometer
- Non-sun synchronous orbit
- ~ 70° inclination
- ~ 400 - 500 km altitude
- ~ 4 km horizontal resolution
- 250 m vertical resolution

MISSION: Understand the horizontal and vertical structure of rainfall and its microphysical elements. Provide training for constellation radiometers.

CONSTELLATION SATELLITES

- 8 small satellites with microwave radiometer only*
- 3 hr revisit time
- Sun-synchronous polar orbit
- ~ 600 km altitude

*Some of the 8 small satellites may be replaced by existing radiometers (e.g., SSM/Is, AMSR, etc.)

MISSION: Provide enough sampling to reduce uncertainty in short-term rainfall accumulations. Extend scientific and societal applications.

Overview

Rainfall products

- High spatial/temporal resolution (Weather & hydrology)
- Monthly, 5° scale (Climate model validation, GEWEX)
- Process studies (Important but little activity)

Radiometers deal differently with:

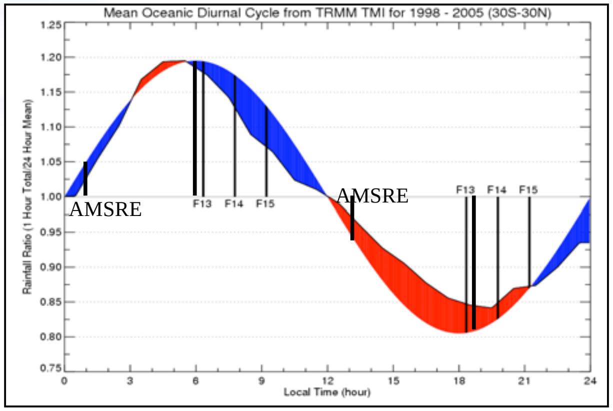
- Oceans (Good relation between liquid water and Tb)
- Land (Ice scattering only)
- Snowfall over land (Ice scattering same as snow on surface)

Need to distinguish between:

- Good signal, and well constrained problem (Does not exist)
- Good signal but poor constraint knowledge (Progress is possible)
- Poor signal (Must find alternate approach)

Passive microwave radiometers have been the workhorse of rainfall remote sensing

- 1987 - present: SSM/I with often more than one satellite
- 1997 - present: TMI (2.5x spatial resolution)
- 2002 - present: AMSR-E (TMI resolution, 2.5x swath)
- 2005 - present: SSMIS (SSM/I w. sounding channels)
- 2006 - present: WINDSAT (good cal., no 85 GHz)
- 1980 - present: MSU/AMSU (sounding channels)



Over oceans, ε ~ 0.5. Raindrop thermal emission is exploited. Good correlation to liquid and some structure info. (~ 100 distinct profile clusters)

Over land, ε ~ 0.9. Raindrops offer no contrast. Must use ice scattering effect plus empirical models for ice/rain relations. Variable surface emissivity complicates rain estimation - particularly for light rain.

Oceans

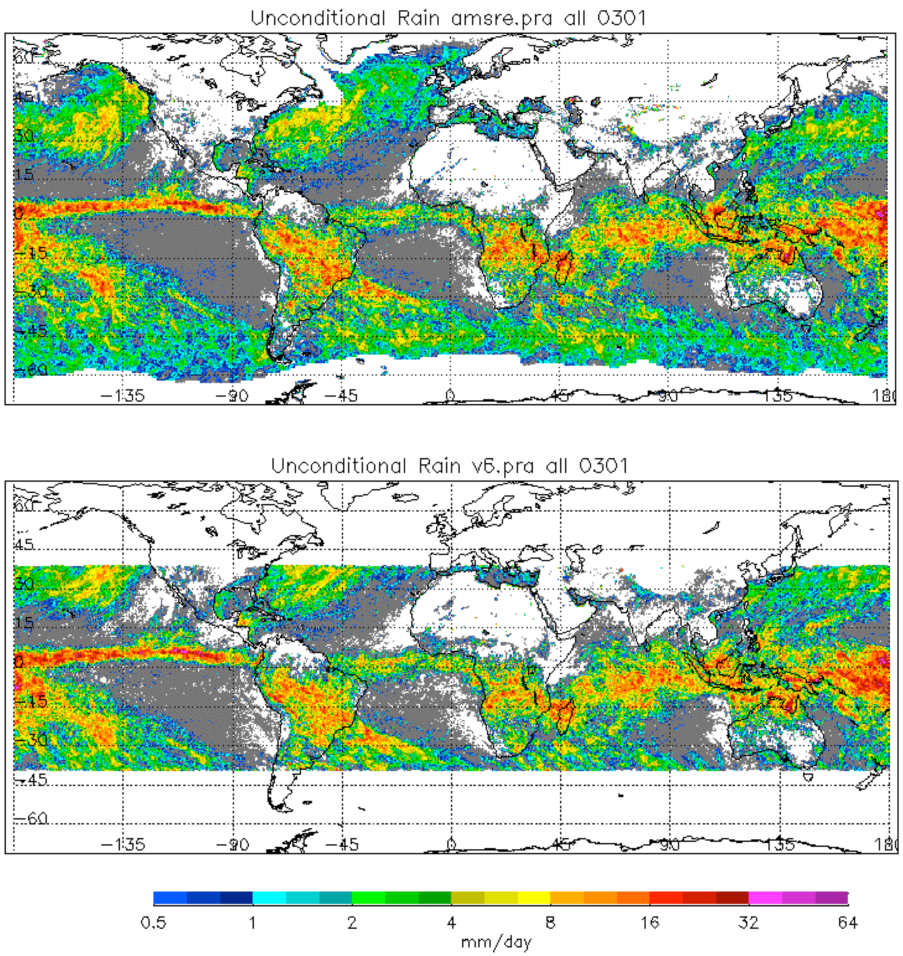
Under-constrained nature of problem solved originally by adding cloud model information to limit vertical structures to possible structures

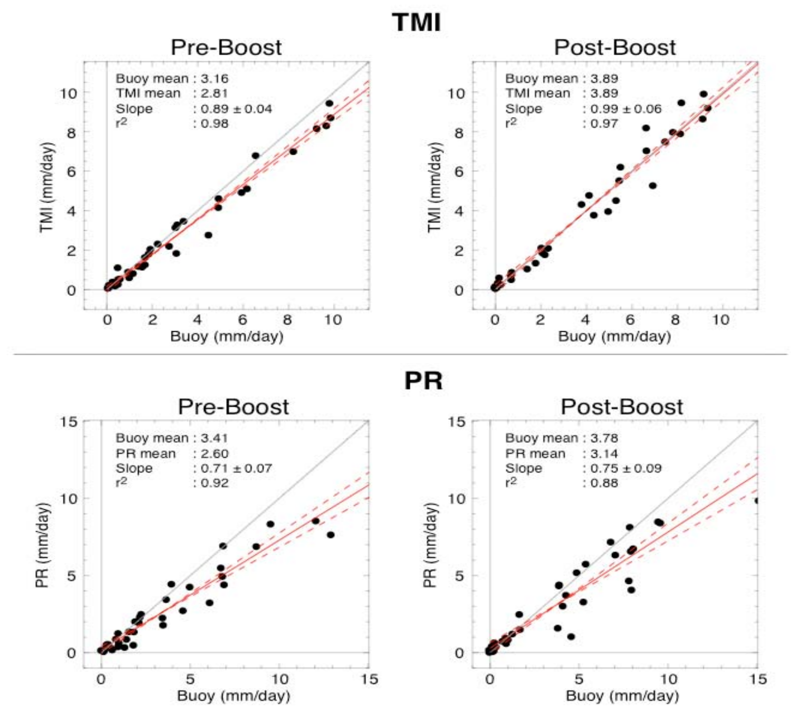
Recently changed to using TRMM radar + radiometer + models to create a-priori that acts as constraint in Bayesian scheme. Multisensor geometry is difficult.

Products are generally quite good w. some caveats

• Previous version (cloud model only) leads to some regional and seasonal (e.g.   ENSO) dependence on climate records that have not been fully resolved between algorithms

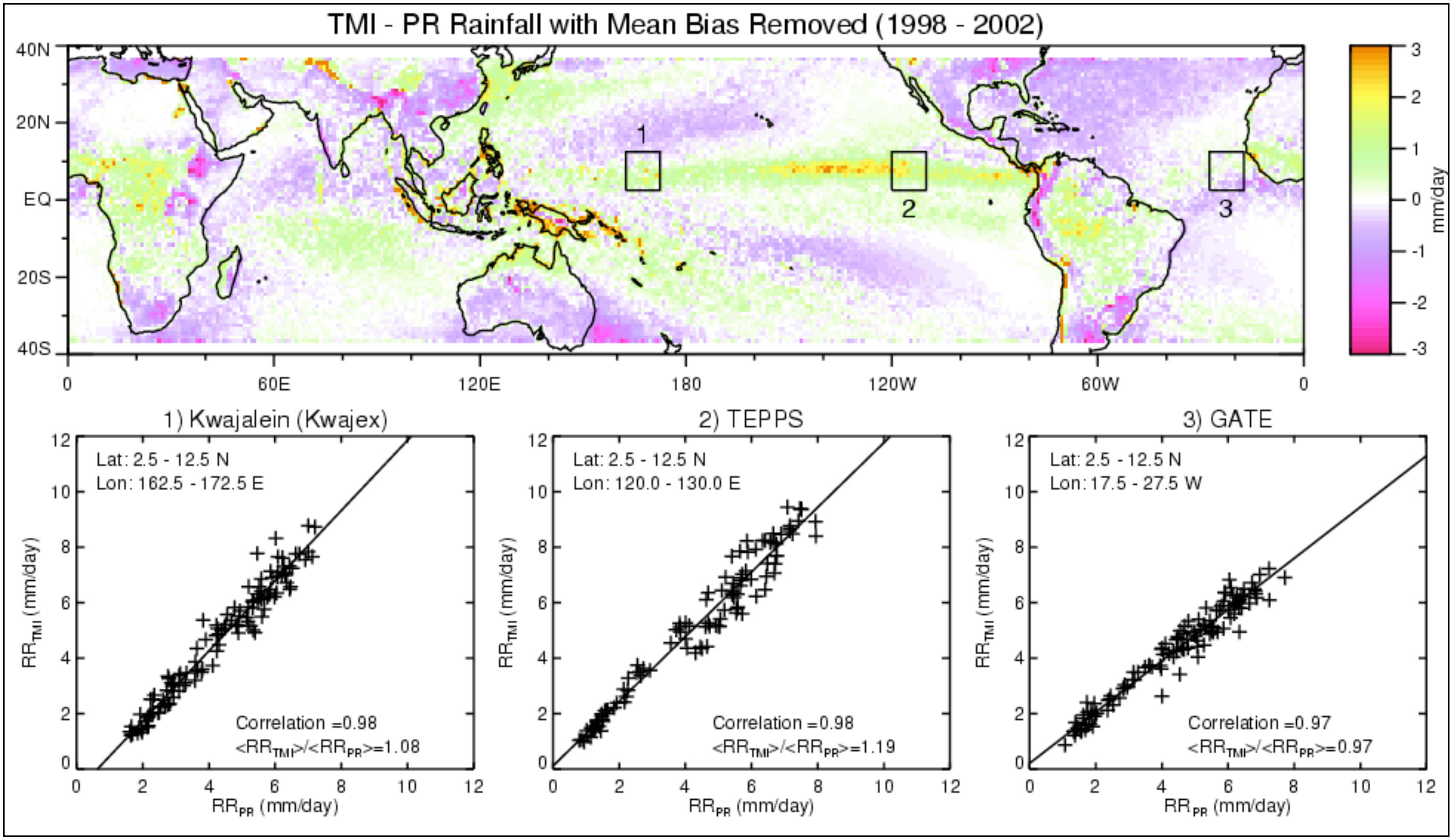
• Radiometers retrieve water content. Sometimes difficult to separate between liquid clouds and precipitation


Unconditional Rain amsre.pra all 0301
Unconditional Rain v6.pra all 0301
0.5
1
2
4
8
16
32
64
mm/day


TMI
Pre-Boost
Buoy mean : 3.16
TMI mean : 2.81
Slope : 0.89 ± 0.04
r2 : 0.98
TMI (mm/day)
Buoy (mm/day)
Post-Boost
Buoy mean : 3.89
TMI mean : 3.89
Slope : 0.99 ± 0.06
r2 : 0.97
TMI (mm/day)
Buoy (mm/day)
PR
Pre-Boost
Buoy mean : 3.41
PR mean : 2.60
Slope : 0.71 ± 0.07
r2 : 0.92
PR (mm/day)
Buoy (mm/day)
Post-Boost
Buoy mean : 3.78
PR mean : 3.14
Slope : 0.75 ± 0.09
r2 : 0.88
PR (mm/day)
Buoy (mm/day)

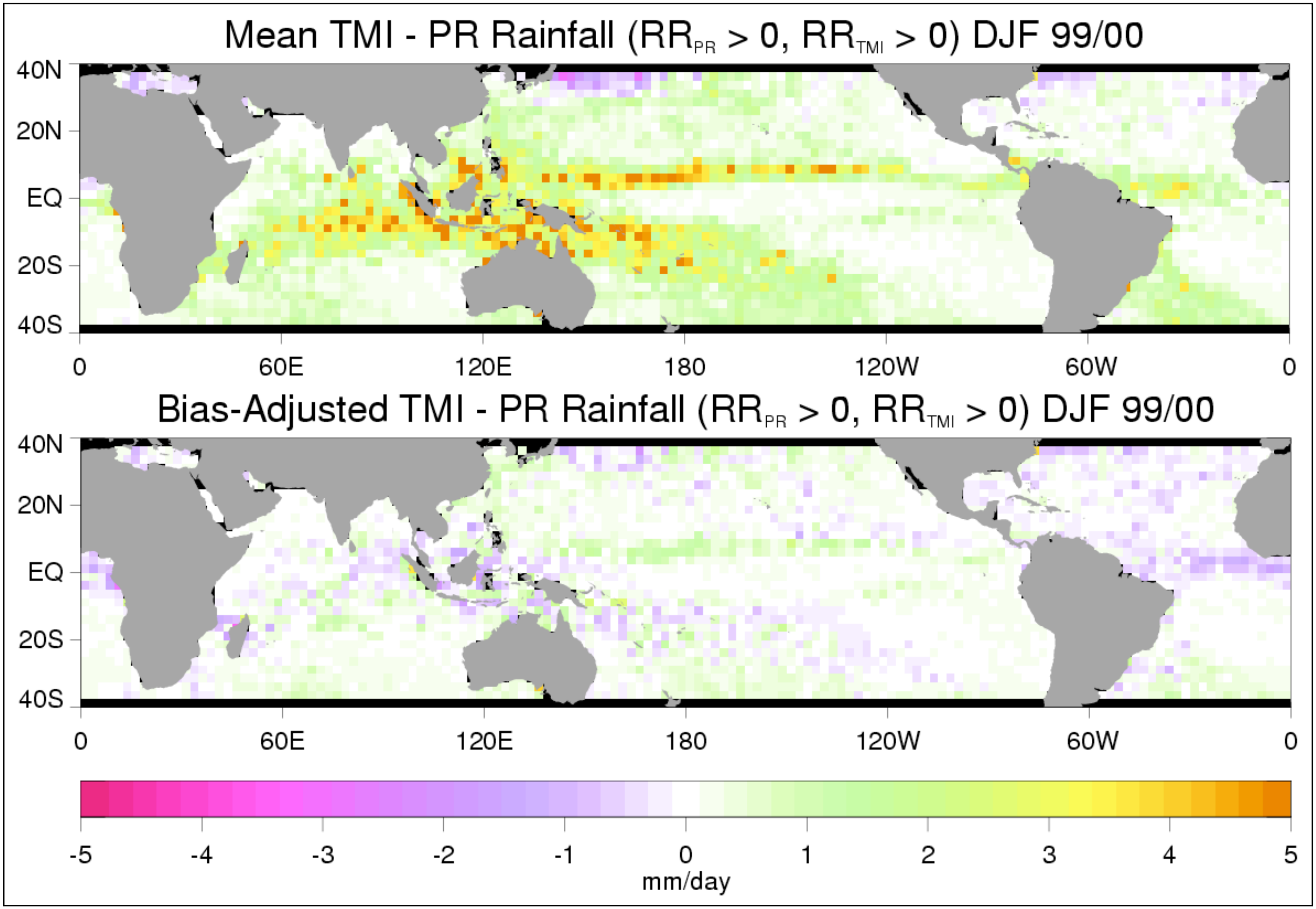
PR/TMI Rainfall Differences

(5-year mean PR-2A25 - TMI-2A12 from 3G68)

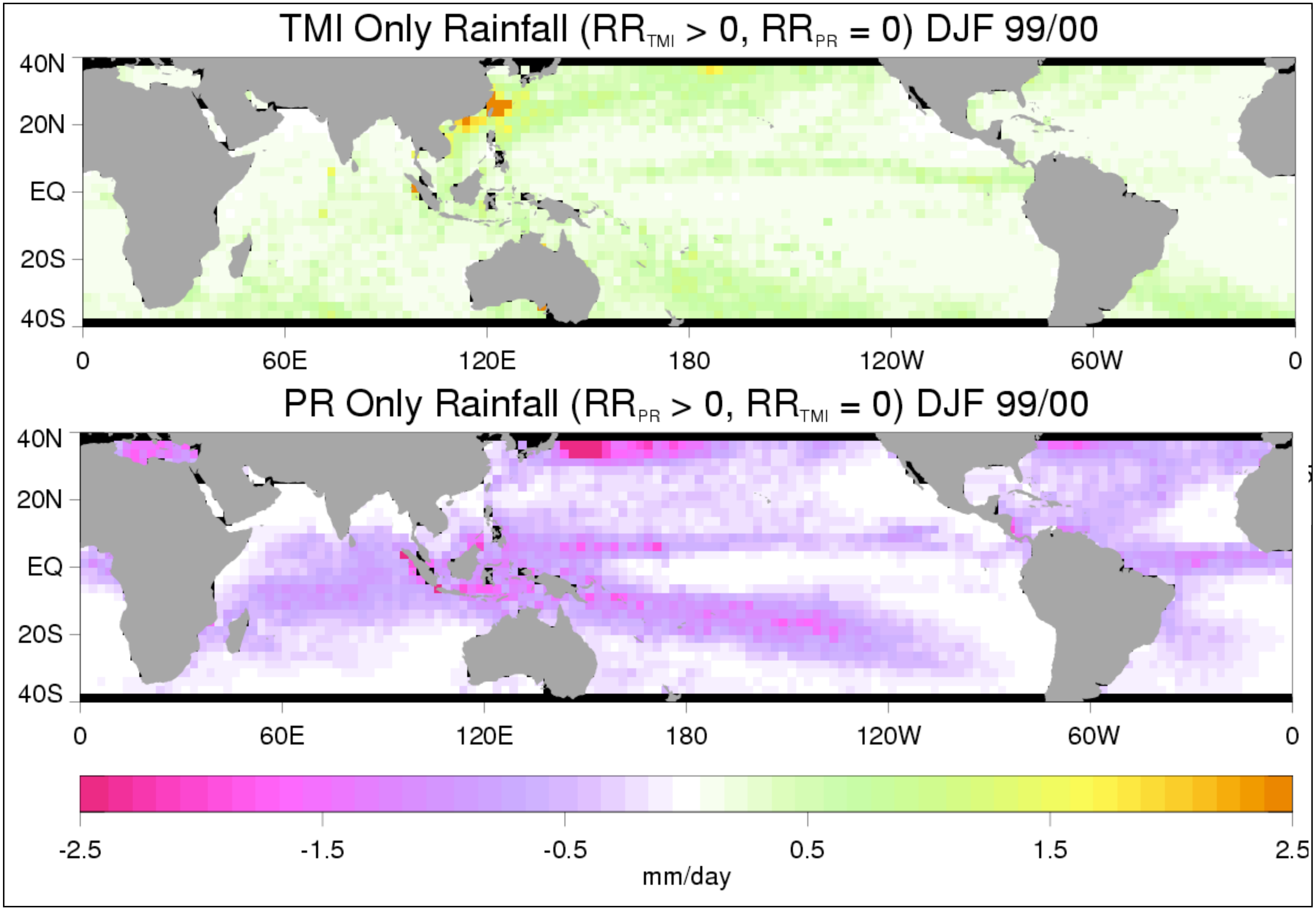


Rainfall Bias Removal

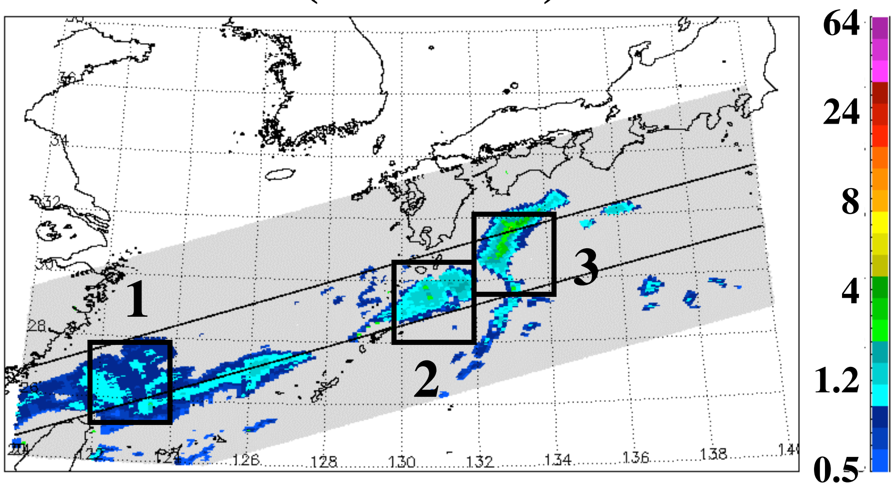
Based on Column Water Vapor



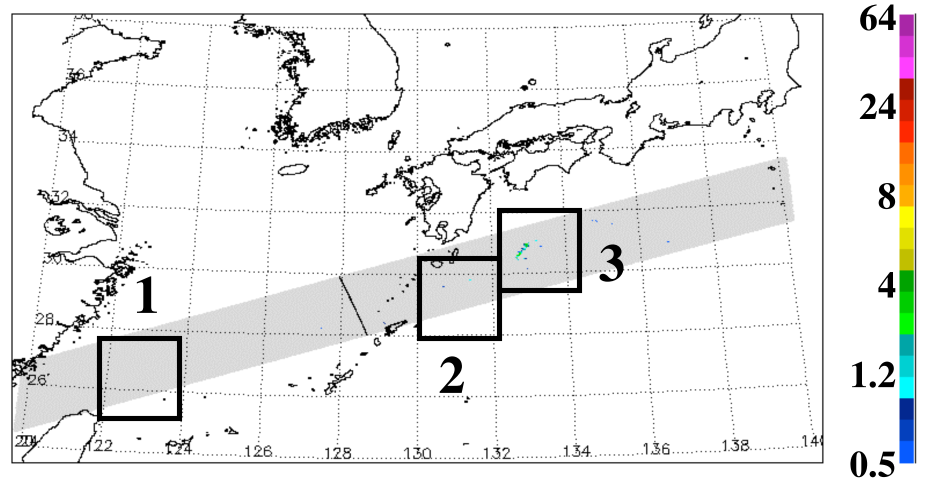
Rainfall Detection Errors



Passive Microwave Rainrate Retrieval (GPROF)

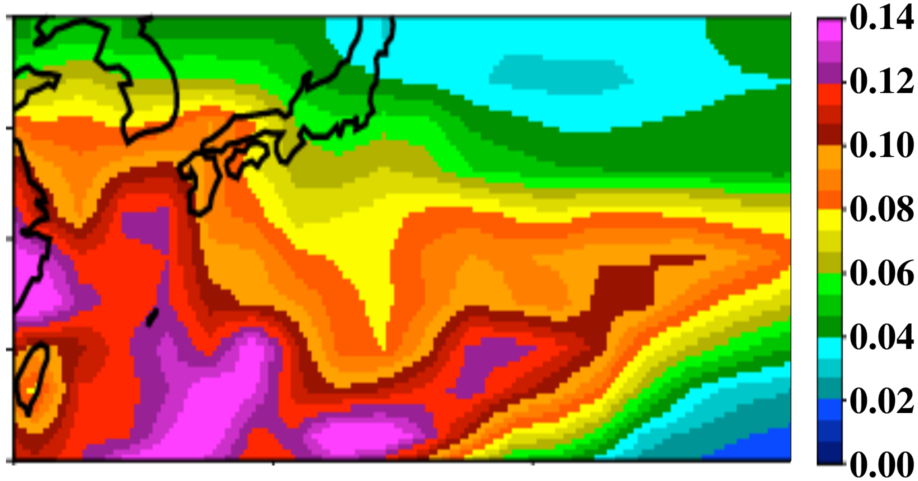


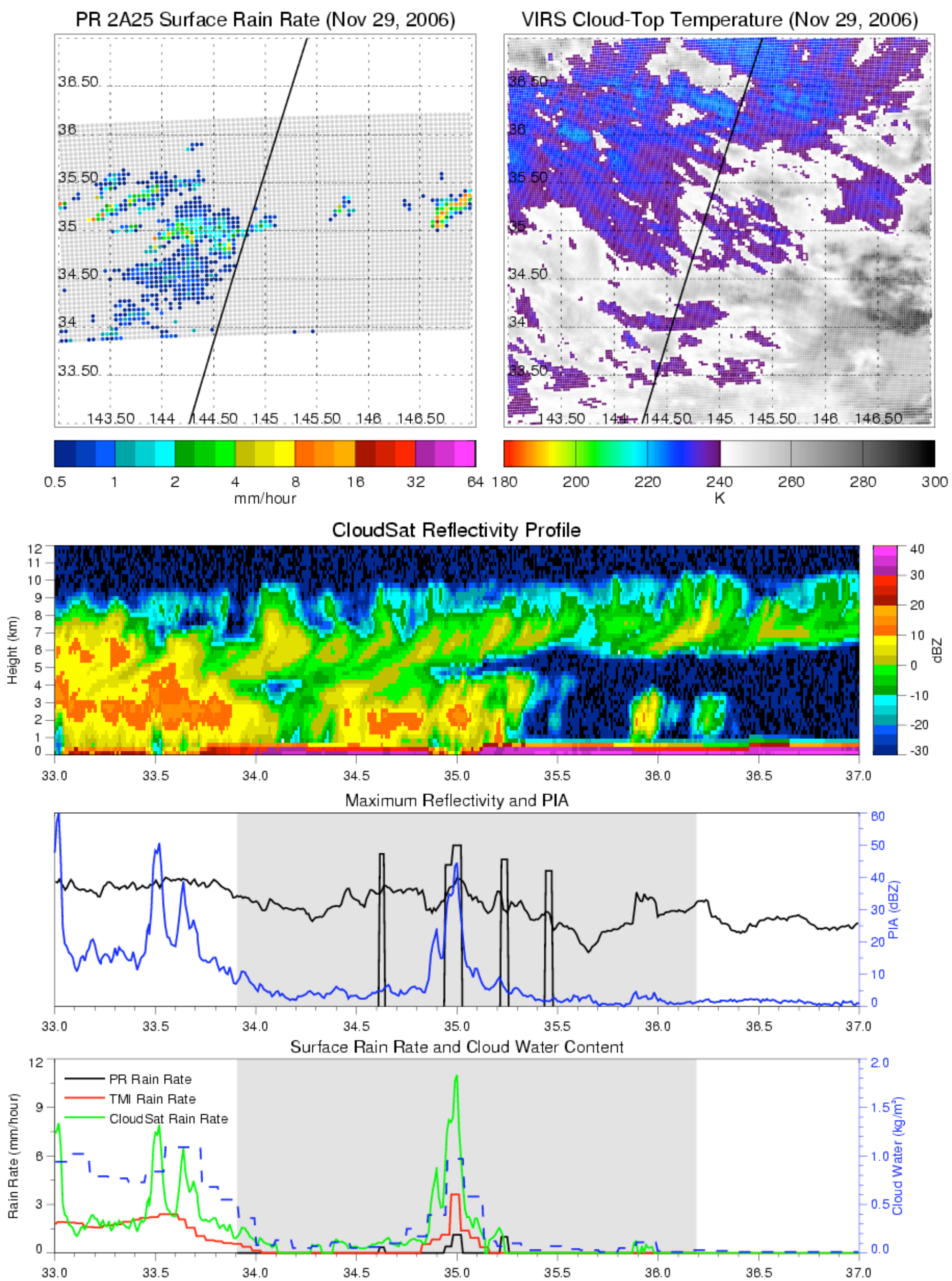
Active Microwave (TRMM PR) Rainrate Retrieval



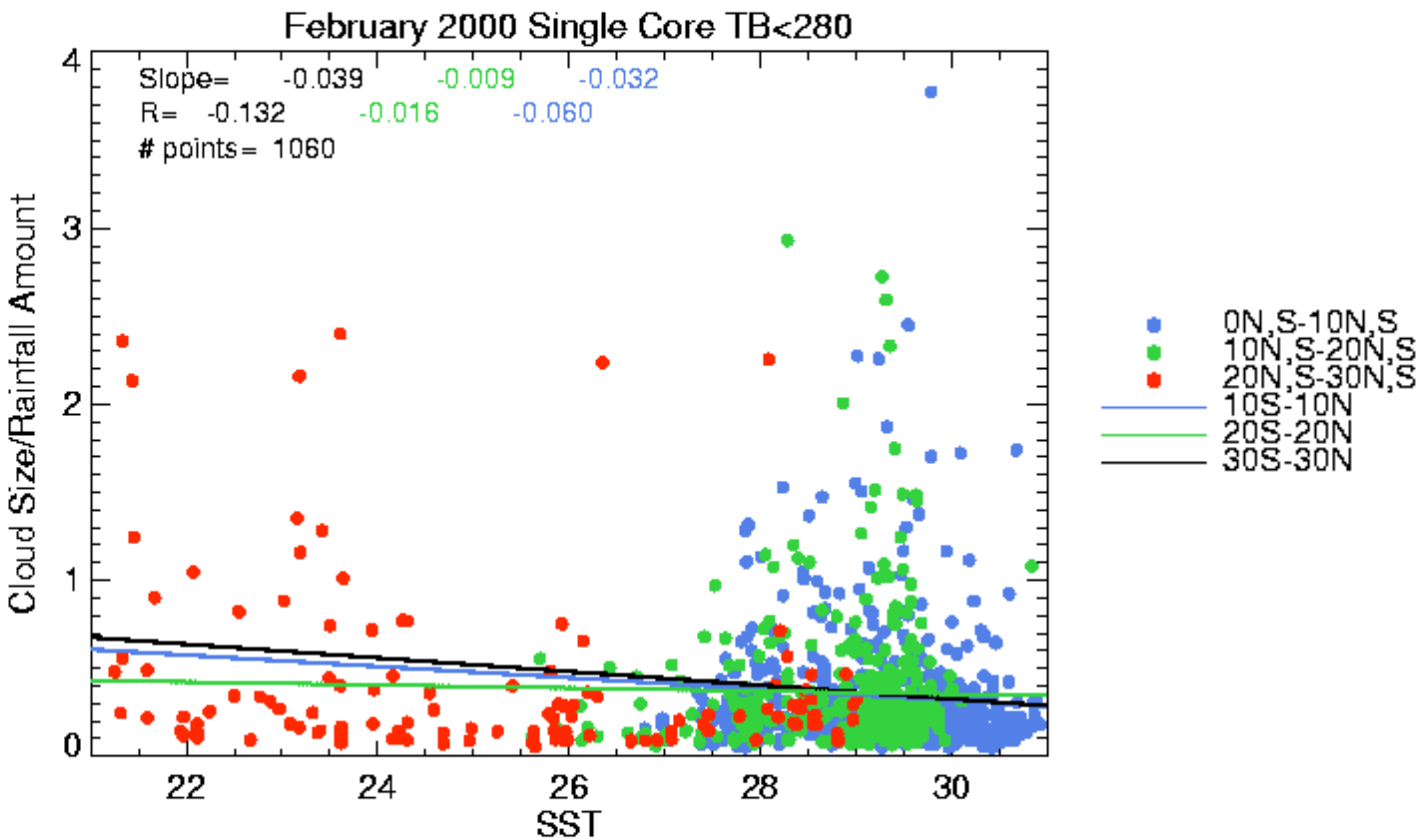
Sulfate Aerosol Optical Depth

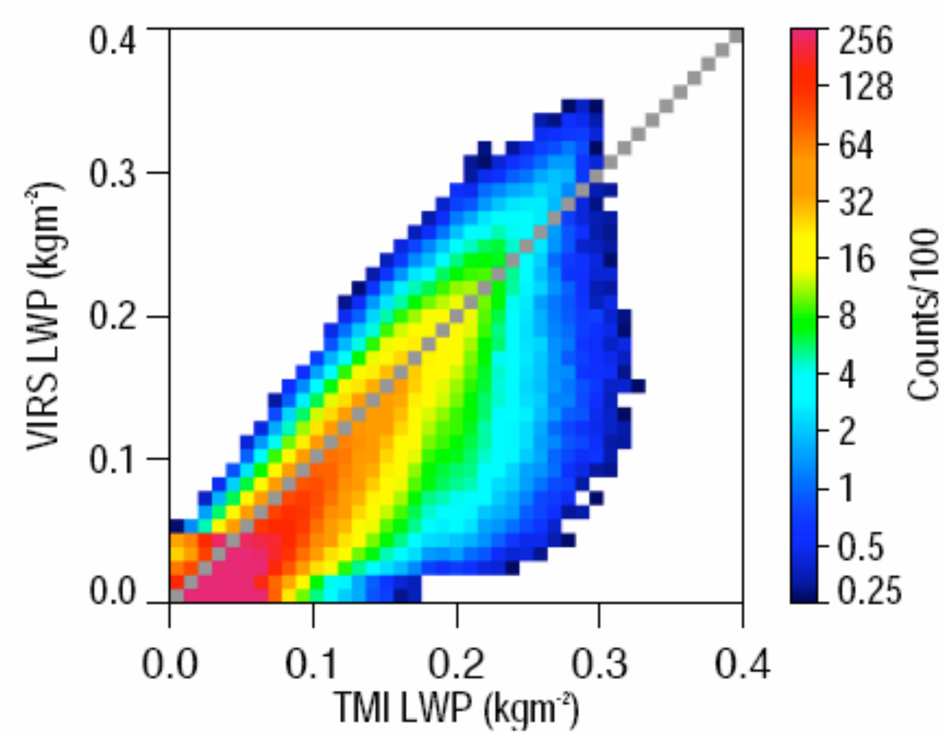
[Berg et al. 2006]

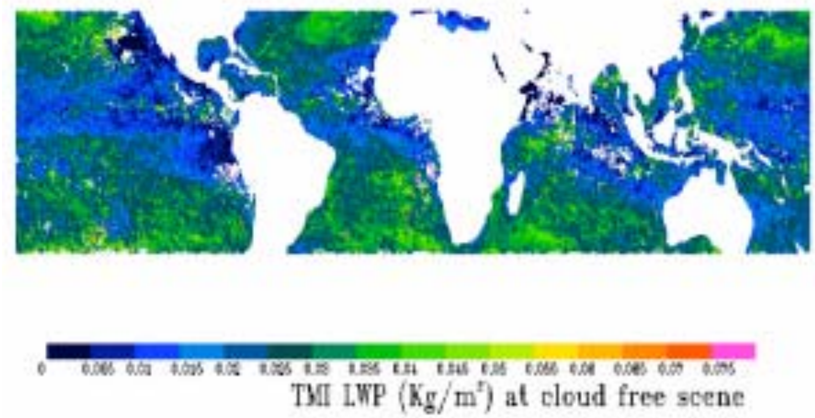


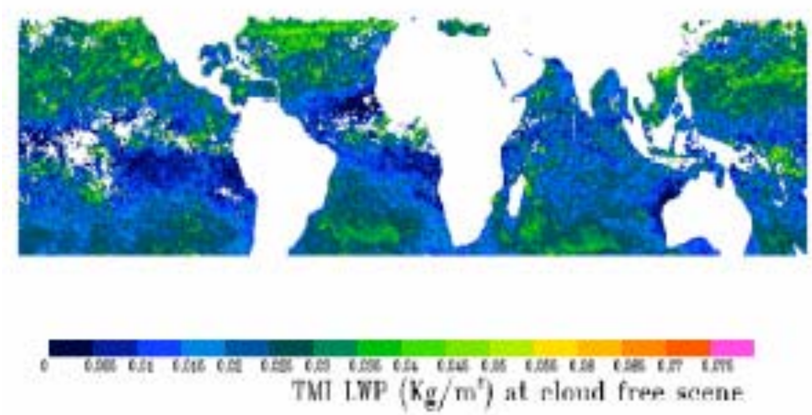

PR 2A25 Surface Rain Rate (Nov 29, 2006)
VIRS Cloud-Top Temperature (Nov 29, 2006)
36.50
36
35.50
35
34.50
34
33.50
143.50
144
144.50
145
145.50
146
146.50
0.5
1
2
4
8
16
32
64
mm/hour
180
200
220
240
260
280
300
K
CloudSat Reflectivity Profile
Height (km)
dBZ
Maximum Reflectivity and PIA
PIA (dBZ)
Surface Rain Rate and Cloud Water Content
PR Rain Rate
TMI Rain Rate
CloudSat Rain Rate
Rain Rate (mm/hour)
Cloud Water (kg/m²)
33.0
33.5
34.0
34.5
35.0
35.5
36.0
36.5
37.0

SST vs. Cloud Area Normalized by Rainfall
Single-Core Convective Clouds TB<280




0.4
0.3
0.2
0.1
0.0
VIRS LWP (kgm⁻²)
0.0
0.1
0.2
0.3
0.4
TMI LWP (kgm⁻²)
256
128
64
32
16
8
4
2
1
0.5
0.25
Counts/100


TMI LWP (Kg/m²) at cloud free scene


TMI LWP (Kg/m²) at cloud free scene

Oceans summary

New databases using combined radar/radiometer/model as a-priori constraints will be useful to resolve (or at least quantify uncertainty) in regional rainfall differences. GPM will help further by providing additional constraints and extending methodology to global atmosphere.

Largest impact may be in quantifying uncertainties in climate variability

Rain threshold problem remains elusive. TRMM radar, radiometer and CloudSat radar are not agreeing. Aerosol impact? Role of SST? Role of dynamics?

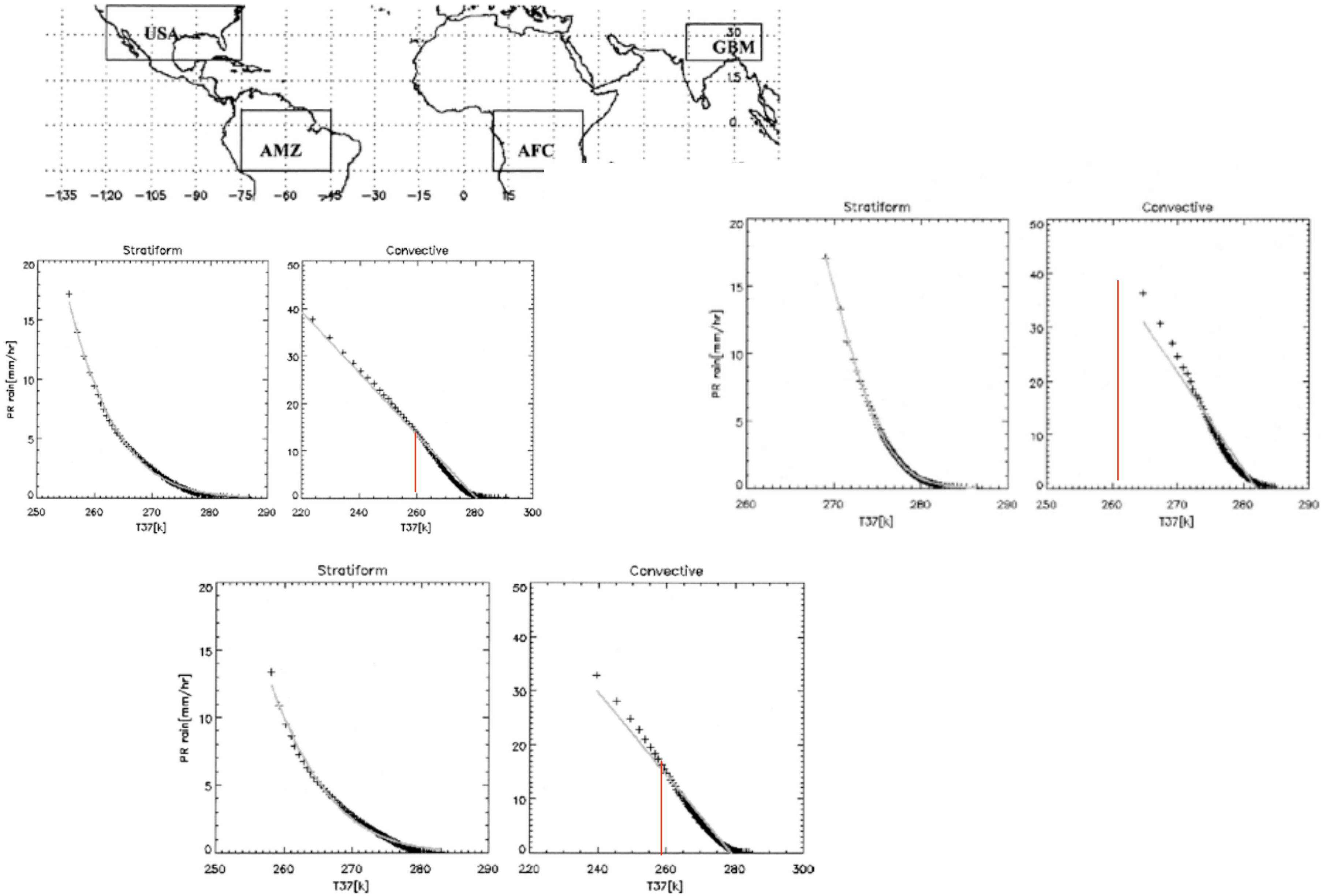
Cloud - rain transition is a “process study”, not a simple cloud or precipitation measurement mission. The biggest impact would likely in climate model parameterizations.

Land

Because emissivity is high, rain offers no contrast against background. Radiometers must rely on ice scattering signature. Radar is useful but not enough sampling to suffice for applications.

Changing from empirical scheme to using TRMM radar + radiometer + models as constraints in Bayesian scheme is difficult because non-raining background is not well characterized (Hydros mission would be very useful if flying in formation) and TRMM radar is not as accurate (GPM will greatly improve).

Current products use universal ice scattering to rainfall relations - best at global scales. Variable ice aloft to surface rainfall relations make it difficult to retrieve rainfall at too fine a time or spatial resolution. May need model input as well to refine ice/rain regime. Will be focus of GPM



USA
GBM
AMZ
AFC
-135 -120 -105 -90 -75 -60 -45 -30 -15 0 15
30
15
0
Stratiform
Convective
PR rain[mm/hr]
T37[k]
Stratiform
Convective
PR rain[mm/hr]
T37[k]
Stratiform
Convective
PR rain[mm/hr]
T37[k]

Land

Must wait for GPM to improve climatology and help radiometers.

Eventually will want to know more about environment and forcing to improve storm scale products.

Light rain is problematic as there is no single threshold for precipitation. Need to learn more about surface emissivity before light rain becomes as difficult as moderate to heavy rain. Hydros would be very useful in formation flight.

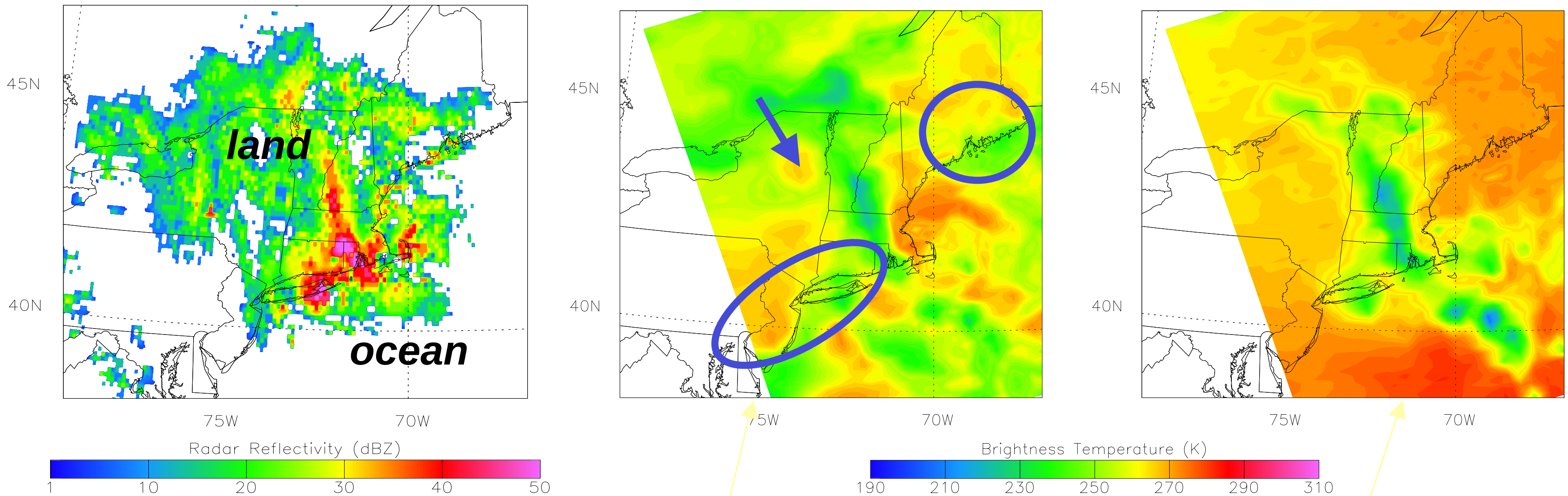
Snow

Similar to light rain problem but further compounded because snow on ground looks similar to snow in the atmosphere.

Need to use sounding channels to avoid surface. Higher frequency channels sense higher in cloud in relationship between surface precipitation and sensed parameter becomes more tenuous. Frequencies become more sensitive to ice microphysics.

March 5-6, 2001 New England Blizzard

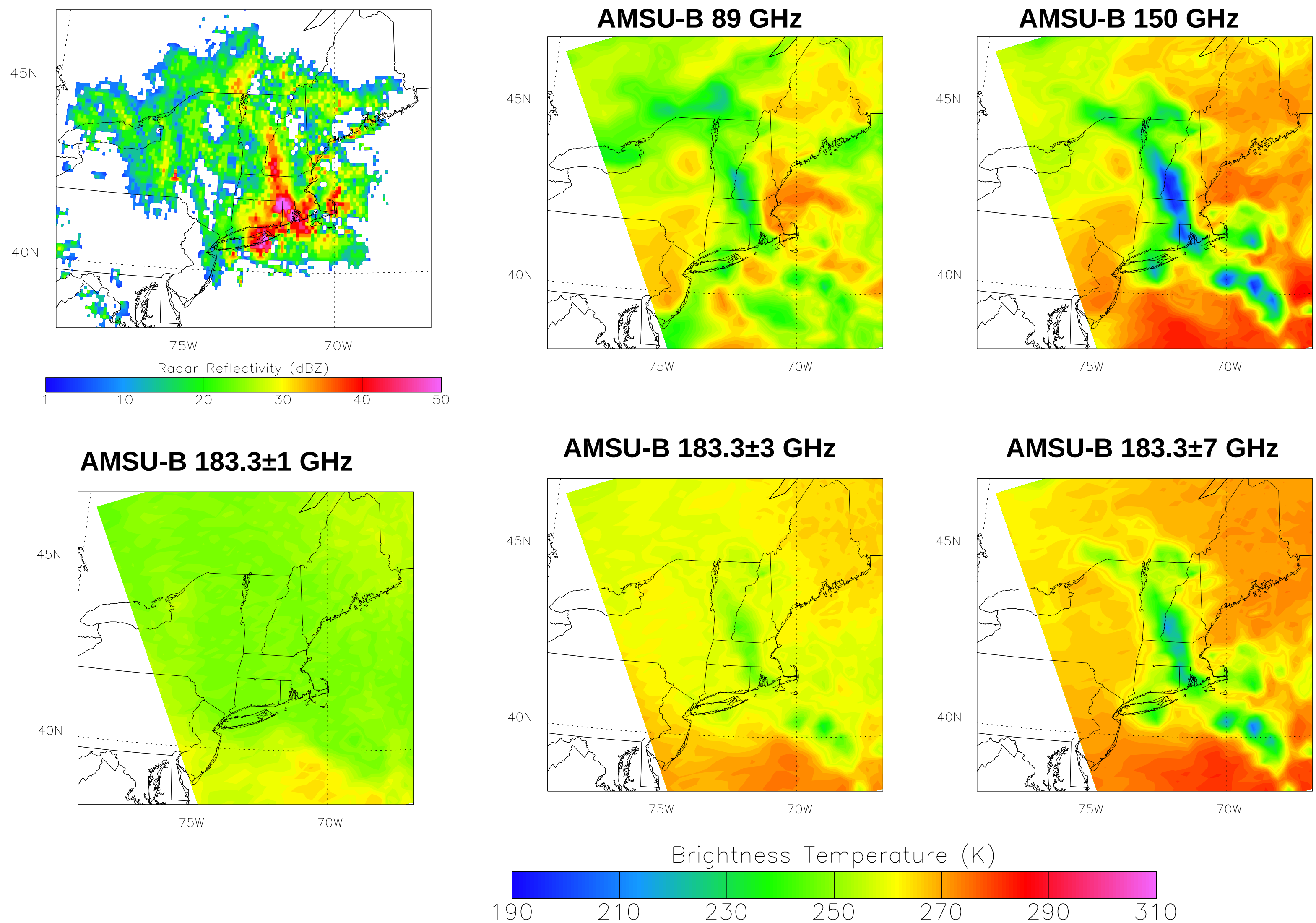
NOAA NWS NEXRAD Data | **AMSU-B 89 GHz** | **AMSU-B 183.3 ± 7 GHz**



- **Surface effect (Ocean/Land)**
- **Hard to discriminate snow storm from ocean surface**

Surface effect was screened out.

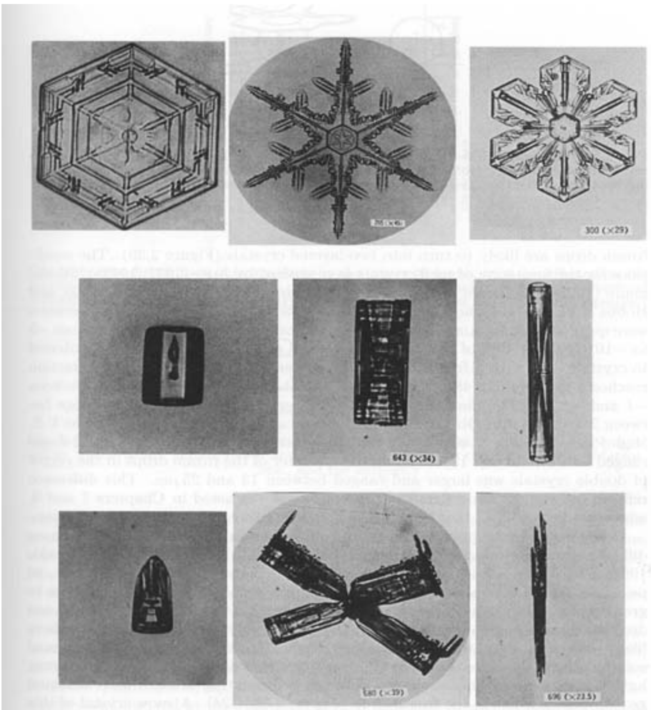
Dependence of 5 Channels on Height



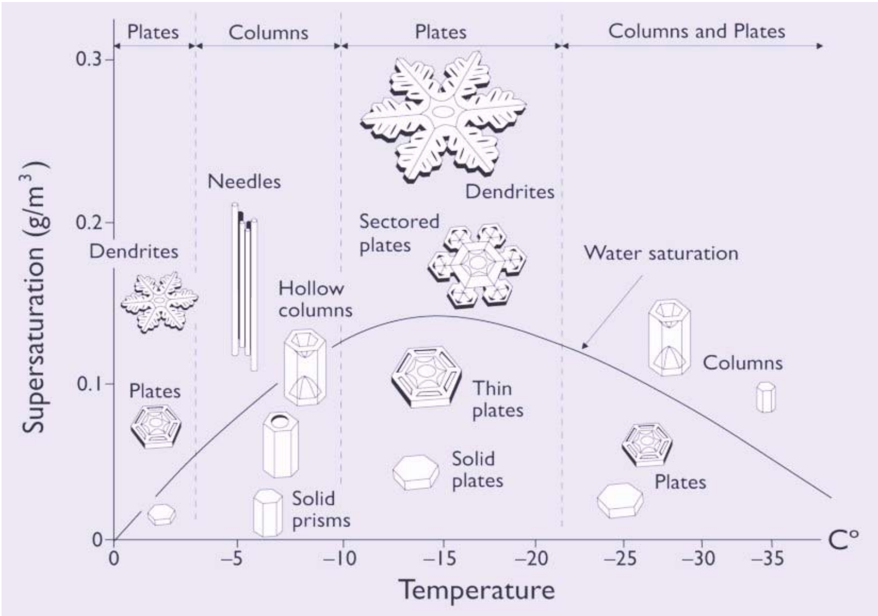
Ice Crystal Habit

NOT SPHERES!

… varying with temperature and water vapor density excess



From Pruppacher and Klett(2000)



Summary

Weather/Hydrology: GPM will improve climate scale products and will help radiometers

- Resolve regional/temporal biases over ocean (or at least quantify the uncertainty)

- Allow moderate rainfall over land to be better quantified globally - although will likely need model guidance for storm scale estimates. Soil moisture mission will help if in formation.

- Make inroads into heavy snow (> 10 dBZ) as seen by Ka radar and microwave sounders

Climate: GPM will improve record by itself and through radiometers

Processes: Need new approaches to solve problems (CAP)

The onset of precipitation - the partition of cloud and rain water - the role of temperature and dynamics - and the effect of aerosols on these processes is perhaps the most pressing question that we could be addressing (especially since it feeds into cloud/aerosol problem and may be useful to advance the snow problem as well).